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SEASONAL FROST HEAVE IN THE MT. RAE AREA OF THE SOUTHERN CANADIAN ROCKY MOUNTAINS

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SEASONAL FROST HEAVE IN THE MT. RAE AREA OF THE SOUTHERN CANADIAN ROCKY MOUNTAINS

INTRODUCTION

The nature of soil displacements due to seasonal frost heave and subsidence in alpine regions of the western Canadian cordillera remains poorly understood. S. Harris (1972, 1973) attempted to establish heaving patterns associated with soil creep in several areas of the southern Rockies but met with limited success. MacKay and Mathews (1974) found that frost heave was insignificant in their study of sorted stripe movement in the Coast Mountains of southern B.C. Despite these findings, research programs completed in other alpine areas have repeatedly emphasized the importance of seasonal frost heave. In particular, Benedict (1970) and Fahey (1974) working in the Colorado Front Range illustrated heave displacements of up to 30 cm annually.

The purpose of this paper is to present the results of several years of study of frost heave in a high mountain area of western Canada. These measurements complement long-term mass wasting studies in the same area by providing an estimate of the importance of local frost creep processes.

FROST HEAVE PROCESSES

Frost heave results from the growth of ground ice within a freezing soil. The smallest fraction of the overall heave is due to volumetric increases of about 9 percent resulting from the freezing of in-situ pore water (Taber, 1930). Thus at a minimum a body of soil can increase in volume in proportion to the amount of pore water present (Andersland et. al., 1978). However, freezing of even a saturated soil can produce a mere 3 percent expansion due to the physical properties of the soil (Sayward, 1979).

The bulk of frost heave is due to the growth of segregated ice at the freezing front. This ice develops as a function of thermal imbalances between the

frozen and unfrozen soil (Konrad, 1980). This phenomena results in moisture migration from the unfrozen soil to the freezing front interface where it accumulates as ice lenses (Konrad and Morgenstern, 1980). Continued advance of the freezing front causes rhythmic ice lensing and a large volumetric soil expansion. In summary, the intrinsic controls most important in defining frost heave magnitudes are the physical properties of the soil, the rate of advance of the freezing plane and the availability of soil moisture.

THE FIELD AREA

The Mt. Rae area (Lat. 50° 35', Long. 114° 58') is situated some 75 km southwest of Calgary (FIGURE 1). It represents one of the most easterly segments of high alpine country found in the front ranges of the southern Canadian Rockies. Mountains in the area are composed of thrust faulted sedimentary strata ranging in age from Devonian to Late-Cretaceous (Allan and Carr, 1947). While there is every indication that deglaciation of local valleys was completed by 13,000 yrs. B.P. (Ferguson and Osborn, 1981), many of the local summits above 2250 m asl likely stood as nunataks during late-Wisconsin time (Jackson, 1980). At Highwood Pass (2208 m asl) the mean annual air temperature is -1.9° C (1966-1973). Precipitation averages 860 mm yr^{-1} (1969-1980), with over 60 percent falling as snow.

Site Description:

In July of 1980 two frost heave study sites were established above timberline. One site (designated "Highwood Ridge") is on an exposed windswept alpine bench located 2340 m asl. The bench dips gently to the northeast and is underlain by a deeply weathered Triassic-aged shale. Active frost boils and permafrost have previously been documented at this site (Smith, 1979). Low growing alpine vegetation, such as arctic willow (salix arctica), snow willow (salix nivalis) and mountain avens (dryas octopetala), dominates the site.

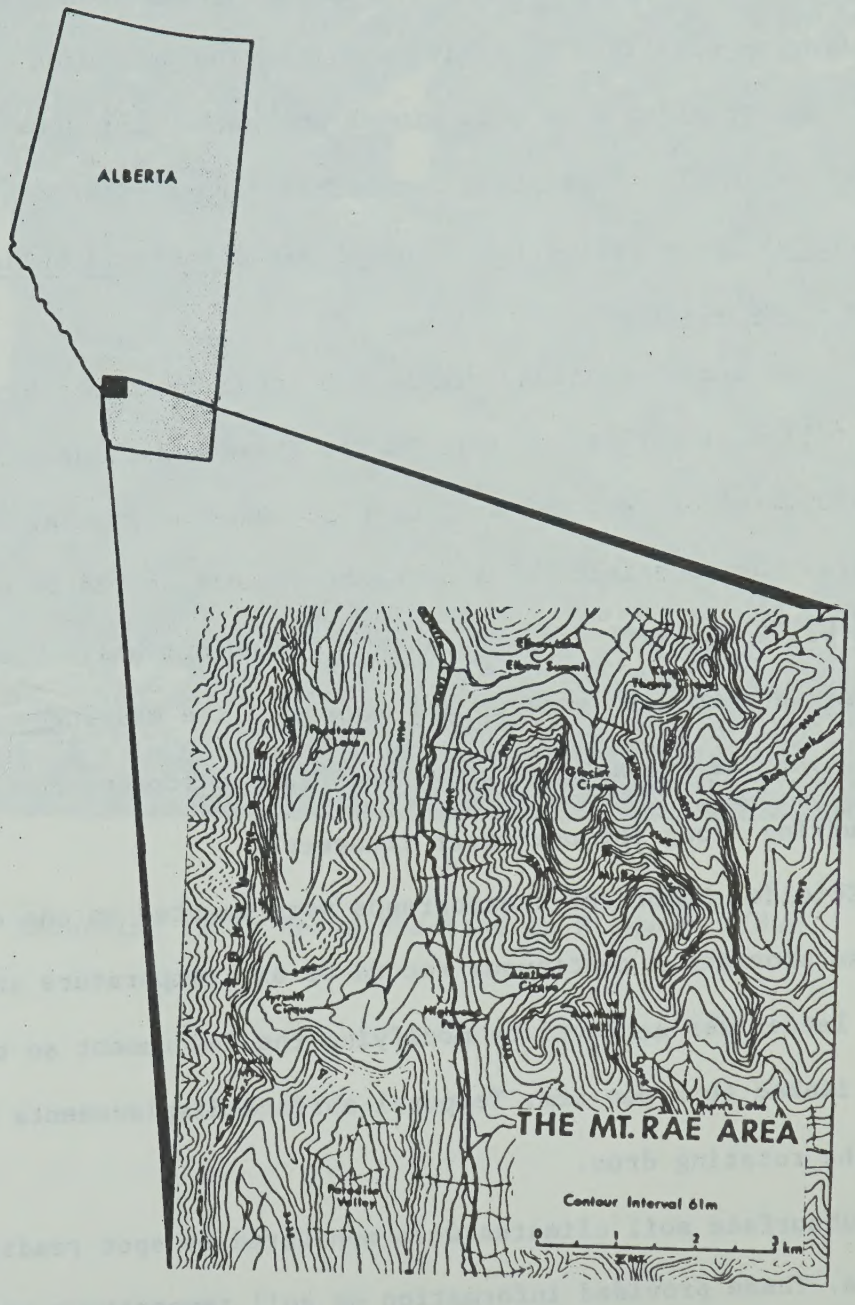

FIGURE 1 : Location Map.

The second site (designated "K2") is located across the valley from the first near the summit of a ridge of Cretaceous sandstone and coal at 2440 m asl. The site dips moderately to the northwest and is mantled by weathered colluvium mobilized by active solifluction processes (Smith, 1982). The site is characterized by a deep winter snowpack which does not completely melt until mid-July. Vegetation communities are dominated by arctic willow (salix arctica), snow willow (salix nivalis)and kobresia bellardi.

Instrumentation:

Frost heave bedsteads similar to those described by C. Harris (1971) were installed at both sites (FIGURE 2). These bedsteads were designed to permit measurement of vertical soil displacements at regular intervals over several years. They consisted of a metal crosspiece bolted to a pair of legs rooted 1 m below the soil surface. A set of aluminum heave rods passing through this frame were free to move up and down with the heaving soil. Periodic measurements of the rod heights above the frame describe vertical displacements occurring along the one meter transect.

Shielded Lambrecht thermographs were mounted on one end of the bedsteads. These provided a continuous record of air temperature and soil displacement. The latter was achieved by modifying the instrument so that one heave rod was linked to a pen arm. Temporal surface displacements were then recorded on the rotating drum.

Subsurface soil climates were monitored by spot reading SoilTest Colman units. These provided information on soil temperature and moisture at depths of 5, 25, 50 and 75 cm. This information was checked against that obtained with a YSI insertion probe and field water content values obtained from soil samples.

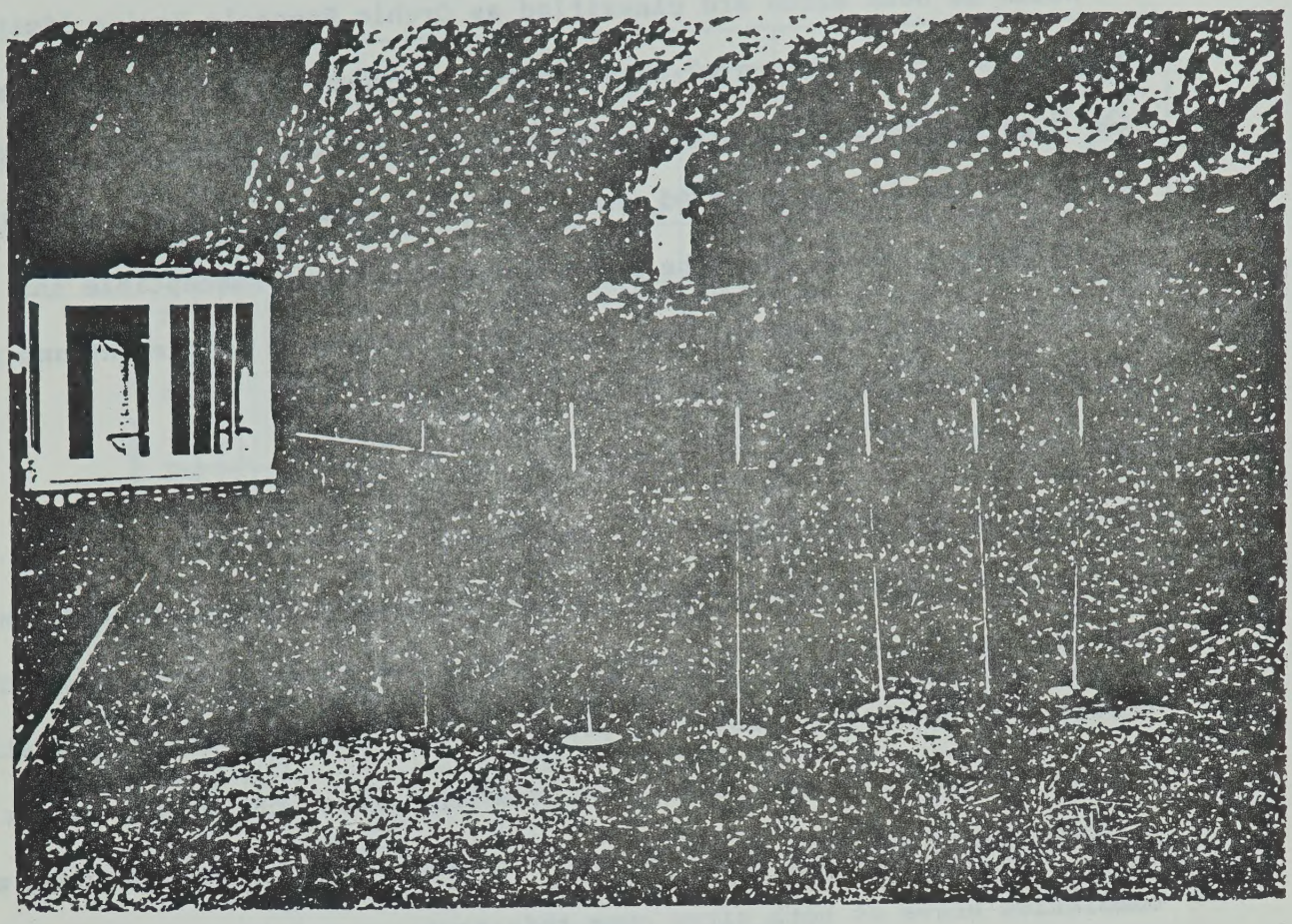

FIGURE 2 : Recording Frost Heave Bedstead on Highwood Ridge.

Soils:

Soils at both sites are classified as Orthic Regosols having limited Ah development. Examination of their physical properties indicated soils from the Highwood Ridge site are highly frost susceptible silty clays (FIGURE 3). Their low liquid limits of 45 percent are balanced by a wide plasticity index of 18 percent. Soils from the K2 site are less frost susceptible and classified as silty sands. They have liquid limits of 72 percent and a plasticity index of 6 percent.

RESULTS

Frost Heave and Subsidence:

Figure 4 illustrates temporal soil displacements at the two bedsteads in the 1980-1982 period. In all cases recorded the greatest precentage of heave occurred in October and November prior to the arrival of large snowfalls. Heaving in the 1980-1981 period continued throughout the winter months with maximum values recorded just before the ground began to thaw. Average maximum cumulative heave at both sites over this period was 4.5 cm.

Magnitudes and patterns of heaving in the 1981-1982 period differ markedly from the previous season. At the Highwood Ridge site displacements achieved by mid-October persisted over most of the winter. Slight increases in heave were recorded prior to melt and attributed to additions of atmospheric moisture at the soil surface. Maximum average cumulative heave achieved at this site in 1981-1982 was only 2.3 cm. The pattern of heave at Bedstead B is less clearly defined due to an inability to visit the site over the winter months. However, average cumulative heave values recorded prior to melt of the winter snowpack were 3.4 cm. These values are 75 percent of those reached in the previous season and are probably indicative of a similar heave regime.

Initial heave values on Highwood Ridge for the 1982-1983 season are sugges-

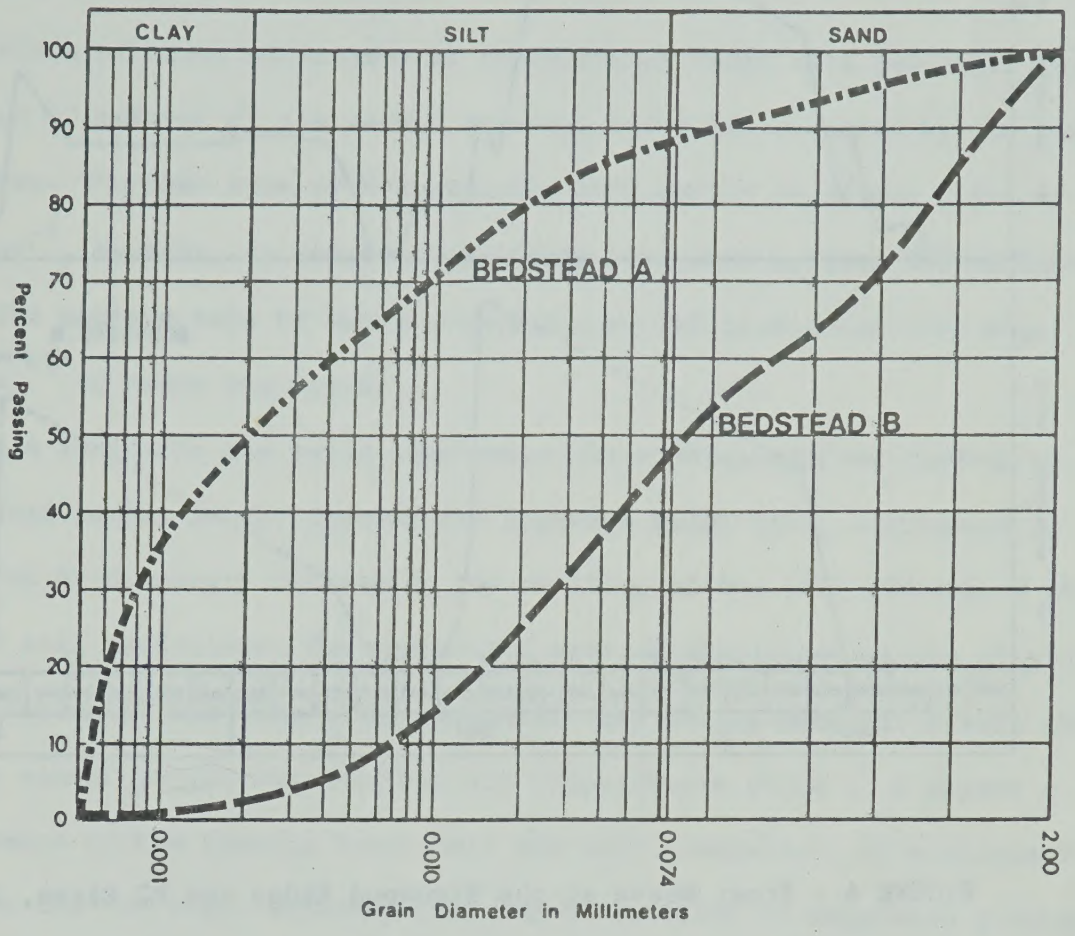

FIGURE 3 : Grain Size Composition of Soils from Highwood Ridge (Bedstead A) and K2 (Bedstead B).

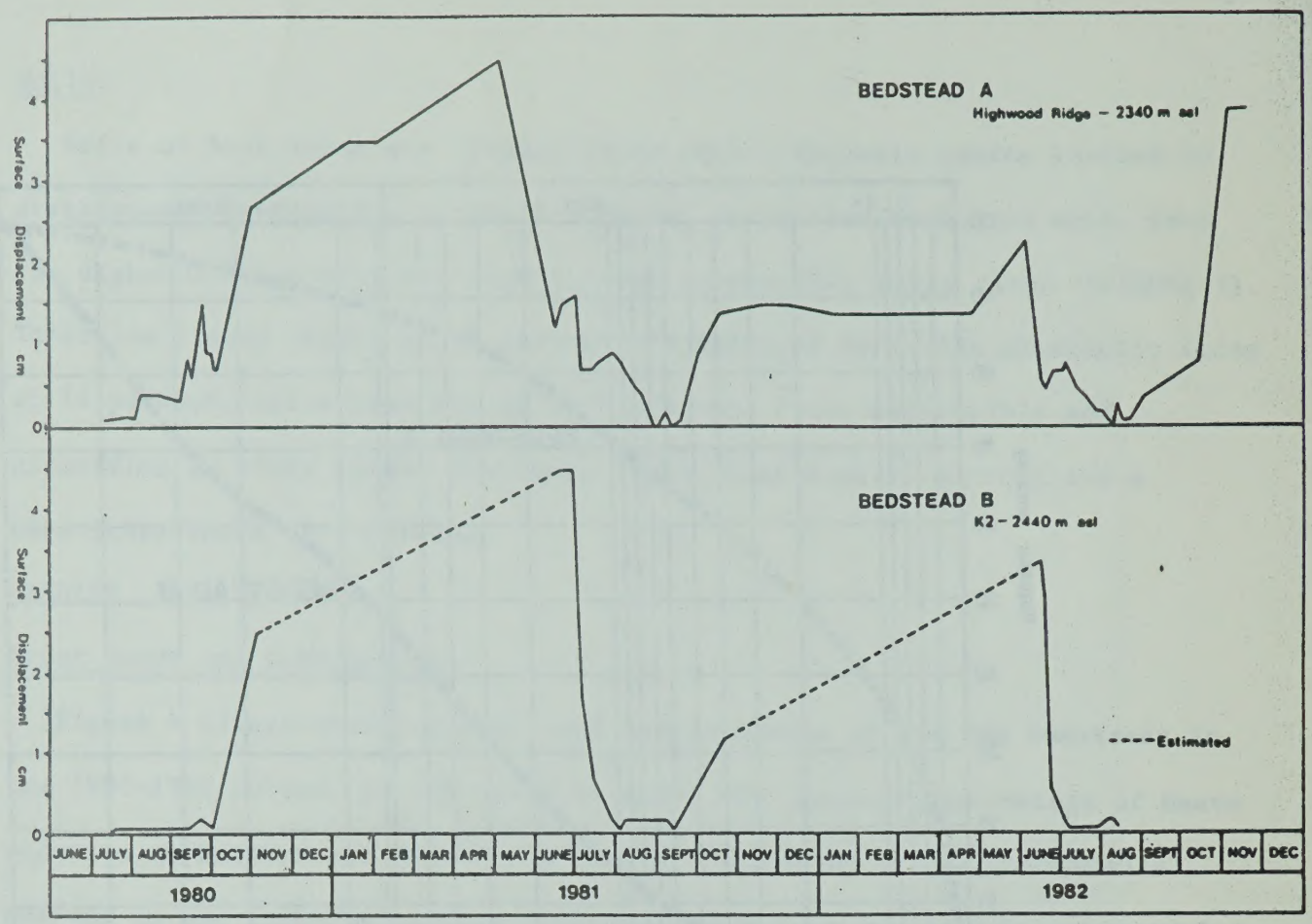
BEDSTEAD A
Highwood Ridge – 2340 m asl
Surface Displacement cm
BEDSTEAD B
K2 – 2440 m asl
Estimated
JUNE JULY AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC
1980
1981
1982

FIGURE 4 : Frost Heave at the Highwood Ridge and K2 Sites, 1980-1982.

tive of substantial displacements. Average cumulative heave by late-November was already 3.9 percent.

Comparison of heave magnitudes at the Highwood Ridge site indicates that on average 62 percent of the annual seasonal heave has occurred by the end of November. The mean rate of heave during this period is in the order of 0.5 mm day^{-1}. However, an order of magnitude separates maximum and minimum values. The maximum rate of heave recorded occurred in October 1982 when 1.0 mm day^{-1} of heave was noted.

Figure 4 indicates the rapid subsidence which characterizes thawing of these heaved soils. In the case of the Highwood Ridge site, settlement is interrupted by temporary refreezing and swelling of the soil associated with saturated soil conditions. The pronounced rate of settlement at the K2 site is a reflection of the late-lying snowpack. This delays subsurface melt until the early summer period when diurnal air temperatures above 0^{o} C ensure a rapid advance of the thawing front into the soil. Comparison of settlement rates from the two sites indicate they can be an order of magnitude greater at the K2 site. At that site rates of settlement have averaged 2.8 mm day^{-1} but attained maximum values of 4.6 mm day^{-1}.

Frost Penetration and Thawing:

Annual variations in thermal conditions at the Highwood Ridge site are presented in Figure 5. The winter period of 1980-1981 was characterized by frequent ambient air temperature shifts around 0^{o} C. In combination with significant snowfall accumulations early in the season, these warm air temperatures resulted in a slow advance of the freezing front (5 mm day^{-1}) and the persistence of relatively warm subsurface winter temperatures. More extreme climatic conditions in 1981-1982 caused a rapid sinking of the 0^{o} C isotherm (11 mm day^{-1}) and the development of very low subsurface temperatures. In 1982-1983

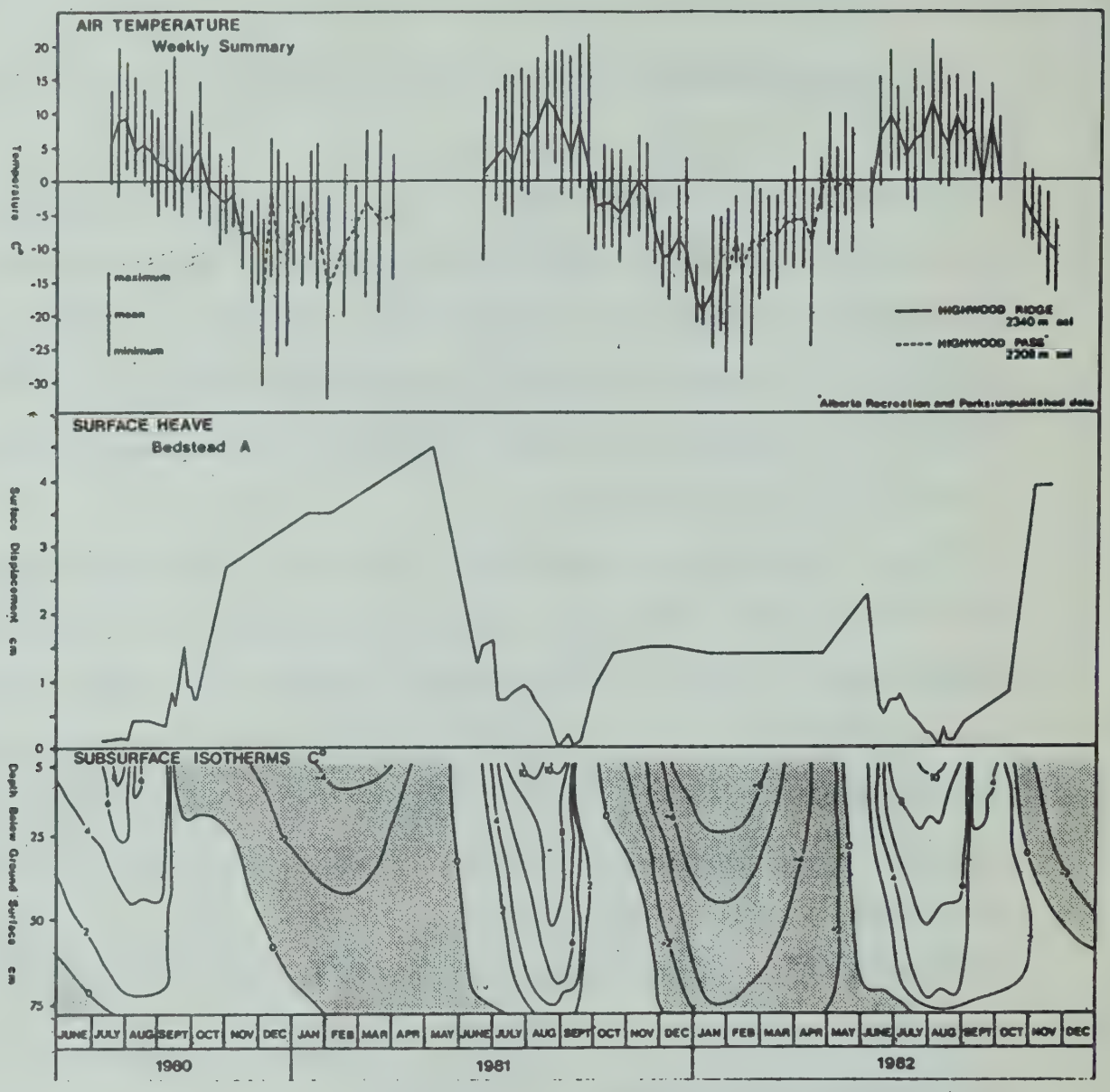

FIGURE 5 : Air Temperature, Frost Heave and Soil Temperature at the Highwood Ridge Site, 1980-1982.

following a very rapid decline in the average air temperatures in early October, the greatest rate of advance of the frost line was recorded (25 mm day^{-1}).

Thaw penetration rates during the spring melt period can be estimated from Figure 5. Following the rapid rise of average air temperatures in April and May, diurnal thaw and nocturnal refreezing of the uppermost soil layers is indicated. By mid-June descent of the thaw line is rapid, often by as much as 10 to 20 mm day^{-1}. In the case of the K2 site, where melt begins over a month later, thaw rates are even faster. In the 1981 and 1982 thaw seasons rates of melt averaged between 45 to 52 mm day^{-1}.

DISCUSSION

The magnitudes of frost heave recorded in the Mt. Rae area are low when contrasted to comparable studies in the Colorado Front Range (Benedict, 1970; Fahey, 1974). Considering in particular their year-to-year variability, it is proposed that the predominate control on these magnitudes is the availability of soil moisture during the freezing period (c.f. Harris, 1972; Fahey, 1979). Evidence for this comes from an examination of soil mositure fluctuations at the Highwood Ridge site.

As shown in Figure 6, in general moisture contents in the uppermost levels of the soil beneath the bedstead are at their highest during the early spring when ground ice and snow are melting. Over the summer months soil mositure levels drop due to drainage and evaporation, although temporary increases related to summer rainstorms are apparent. Generally, the deeper soil levels illustrate moisture changes with an almost reverse pattern. In their case net moisture percentages gradually recover from lower springtime values. Presumably this situation reflects water losses due to migration in the freezing period. While downward water movement to the underlying permafrost

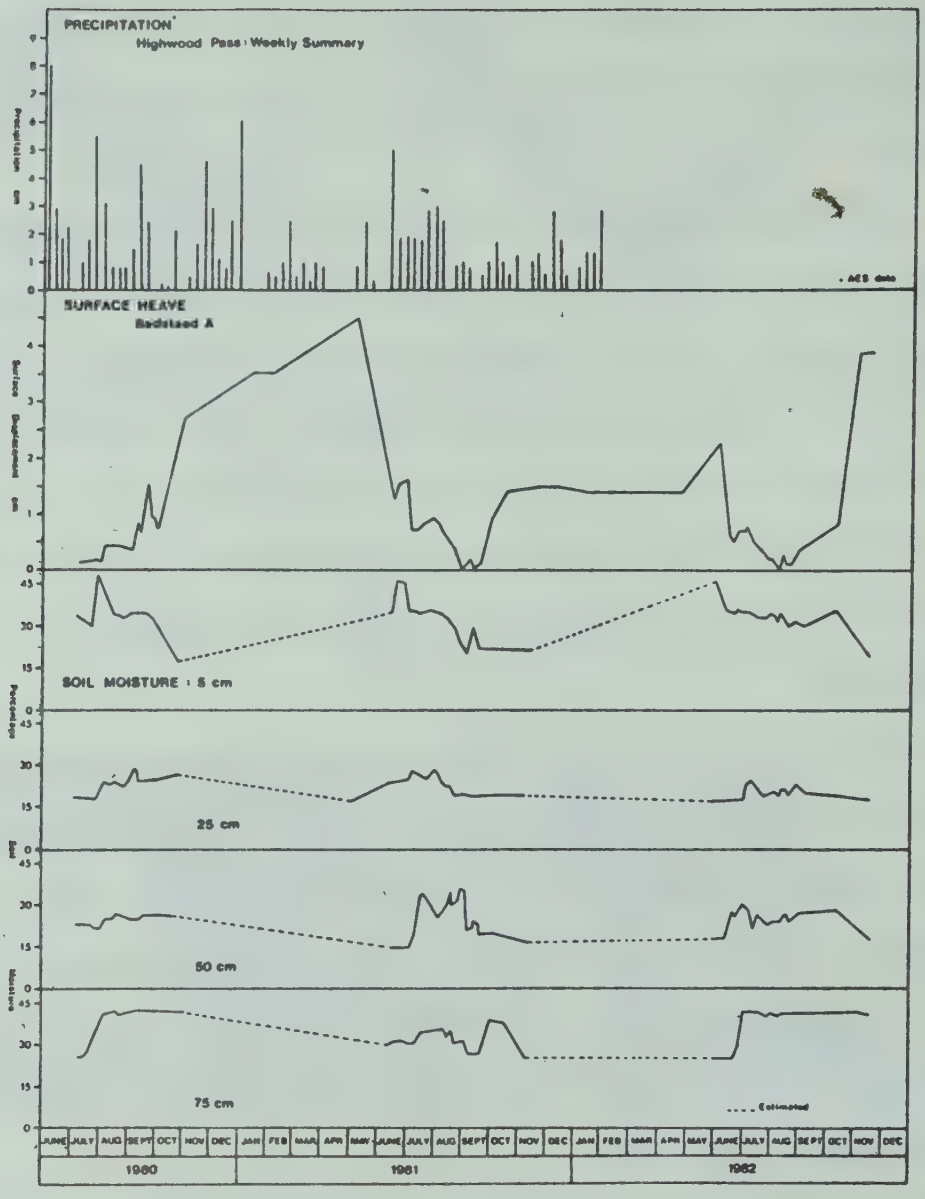
PRECIPITATION
Highwood Pass : Weekly Summary
SURFACE HEAVE
Bedstead A
SOIL MOISTURE : 5 cm
25 cm
50 cm
75 cm
Estimated
JUNE JULY AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC
1980
1981
1982

FIGURE 6 : Precipitation, Frost Heave and Soil Moisture Fluctuations at the Highwood Ridge Site, 1980-1982.

body might account for the depletion observed at these levels (MacKay, 1983); the depth of the active layer (greater than 1.5 m on the average) would seem to mitigate against this process significantly reducing water contents at these relatively shallow depths. Instead, these soil mositure losses must result predominantly from water migration to the downward moving seasonal frost front.

On the basis of these observations it is interesting to consider the fluctuations of soil moisture in relation to the recorded frost heave magnitudes (FIGURE 6). In the case of the Highwood Ridge site it is estimated that at a maximum about 30 percent of the measured heave in 1980-1981 could have resulted from the freezing of in-situ soil mositure. In the 1981-1982 this dropped to 10 percent and in 1982-1983 amounted to around 20 percent. Clearly the largest percentage of heave results from the growth of segregated ice lenses. Hence the differences in heave magnitudes reflect the availability of mositure for migration. Since at very low moisture contents water is held tightly to the surface of soil particles (Farouki, 1981), heave magnitudes during years of low soil moisture will be correspondingly even less. In this regard the 1981-1982 frost heave record is very instructive as it represents the season of lowest heave and soil moisture.

Frost Creep:

In alpine tundra landscapes like those found in the Mt. Rae area, the primary geomorphic significance of seasonal frost heaving relates to the generation of frost creep. Frost creep occurs when a heaved soil is displaced downslope during thaw settlement. The potential frost creep generated by frost heaving can be simply computed (C. Harris, 1981:76). For example, the potential frost creep at the K2 site would have been 1.5 cm in 1980-1981 but only 1.1 cm in 1981-1982. However, maximum rates of downslope activity at this site,

where gelifluction processes are certainly active as well, have averaged 0.5 cm $yr.^{-1}$ (Smith, 1982). At a maximum then the actual frost creep at this site must be less than 30 to 45 percent of the computed values. Thus while it is clear that locally frost heaving contributes to mass wasting activity, it is difficult to distinguish its importance amongst the suite of interacting processes.

CONCLUSIONS

This study demonstrates that seasonal frost heave is an active component of geomorphic activity in the southern Rockies. The relatively low heave magnitudes recorded are most directly related to limited soil moisture prior to the fall freeze-up. In a similar manner, the large year-to-year variations in heave magnitudes discovered are apparently conditioned by annual differences in both the soil and thermal regimes. These observations demonstrate the extent of frost heaving in the Mt. Rae area but leave open the question as to its significance in terms of local mass wasting.

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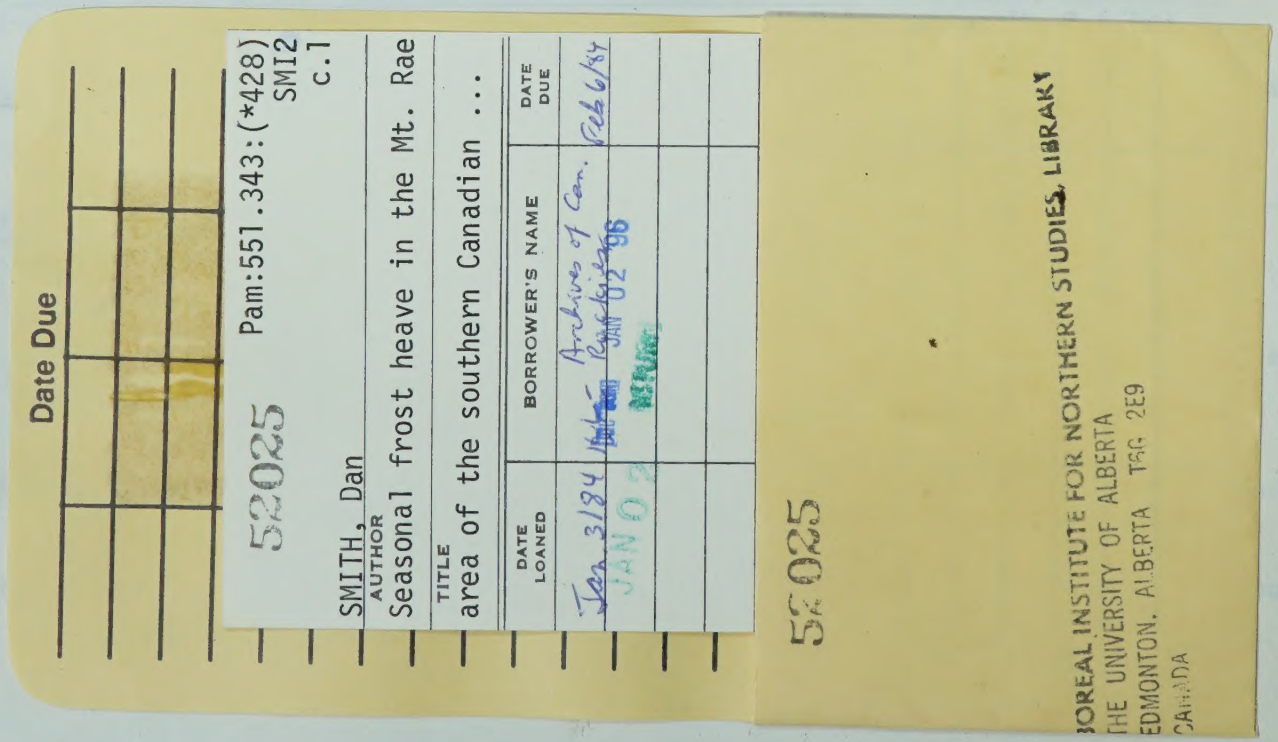
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